California Air Resources Board

Quantification Methodology

**California Air Resources Board
Woodsmoke Reduction Program**

California Climate Investments

Note:
The California Air Resources Board (CARB) is accepting public comments the Draft Woodsmoke Reduction Program Benefits Calculator Tool and the Draft Woodsmoke Reduction Quantification Methodology until December 21, 2018 via GGRFProgram@arb.ca.gov. The Draft Benefits Calculator Tool and Draft Quantification Methodology are subject to change pending stakeholder comments and Final Woodsmoke Reduction Guidelines. The Final Woodsmoke Reduction Benefits Calculator Tool and Final Woodsmoke Reduction Quantification Methodology will be available on the California Climate Investments resources webpage at: http://www.arb.ca.gov/cci-resources.

**DRAFT
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Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

For CARB's Woodsmoke Reduction Program, staff developed this Woodsmoke Reduction Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project. The Woodsmoke Reduction Program is administered by CARB in partnership with the California Air Pollution Control Officers Association (CAPCOA) and local air pollution control districts or air quality management districts (Districts). Participating Districts will help households replace uncertified wood stoves or inserts used as the primary source of heat with cleaner burning and more efficient home heating stoves. For the purposes of the program, a project is defined as the set of change-outs funded by the program within a participating District. This methodology uses calculations to estimate GHG emissions associated with the implementation of Woodsmoke Reduction projects.

The Woodsmoke Reduction Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with a project example, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the Woodsmoke Reduction Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds requested. The Woodsmoke Reduction Benefits Calculator Tool is available for download at: http://www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate GHG emission reductions, the Woodsmoke Reduction Benefits Calculator Tool estimates the following co-benefits and key variables from Woodsmoke Reduction projects: reductions in nitrogen oxides (NO_x) (lbs) and reactive organic gases (ROG) (lbs), and energy and fuel cost savings. Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., reductions in cord wood burned). Additional co-benefits for which CARB assessment methodologies were not incorporated into the Woodsmoke Reduction Benefits Calculator Tool may also be applicable to the project. Applicants should consult the Woodsmoke Reduction guidelines, solicitation materials, and agreements to ensure they are meeting Woodsmoke Reduction requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB developed this Woodsmoke Reduction Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the Woodsmoke Reduction project types. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community

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[1] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines

engagement. As they become available, co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Tools

The Woodsmoke Reduction Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available at: http://www.arb.ca.gov/cci-resources. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the Woodsmoke Reduction Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The Woodsmoke Reduction Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the Woodsmoke Reduction Quantification Methodology from the previous version[2] to enhance the analysis and provide additional clarity. The changes include:

- Included certified pellet stoves or inserts and ductless mini-split heat pumps;
- Added new co-benefits to the output tab in the Benefits Calculator Tool using one of the same inputs used to estimate GHG emission reductions.
- Added a link to a step-by-step user guide with a project example.

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[2] Greenhouse Gas Quantification Methodology for the California Air Resources Board Woodsmoke Reduction Program released September 29, 2017

Section B. Methods

The following section provides details on the methods supporting emission reductions in the Woodsmoke Reduction Benefits Calculator Tool.

Woodsmoke Reduction Project Change-Out Types

The Woodsmoke Reduction Program Guidelines[3] identifies eligibility criteria including the types of old and new home heating stoves that can be funded for which there are methods to quantify GHG emission reductions. This quantification methodology matches those eligibility criteria and quantifies benefits based on the quantity of each type of change-out performed by a District. The different change-out types are:

- Replacing fireplaces with certified non-catalytic wood stoves or wood inserts;
- Replacing uncertified wood stoves or wood inserts with certified non-catalytic wood stoves or wood inserts;
- Replacing fireplaces with certified catalytic wood stoves or wood inserts;
- Replacing uncertified wood stoves or wood inserts with certified catalytic wood stoves or wood inserts;
- Replacing fireplaces with certified pellet stoves or pellet inserts;
- Replacing uncertified wood stoves or wood inserts with certified pellet stoves or pellet inserts;
- Replacing fireplaces with ductless mini-split heat pump;
- Replacing uncertified wood stoves or wood inserts with ductless mini-split heat pump;
- Replacing fireplaces with electric home heating stoves;
- Replacing uncertified wood stoves or wood inserts with electric home heating stoves;
- Replacing fireplaces with propane home heating stoves;
- Replacing uncertified wood stoves or wood inserts with propane home heating stoves;
- Replacing fireplaces with natural gas home heating stoves; and
- Replacing uncertified wood stoves or wood inserts with natural gas home heating stoves.

This methodology estimates the benefits of a project based on the quantities of each type of change-out performed. Districts will therefore need to estimate emission reductions both when awarded and implemented.

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[3] Residential Woodsmoke Reduction Program.
https://www.arb.ca.gov/planning/sip/woodsmoke/reduction_program.htm

1. Awarded Funds: Upon being awarded funds by CAPCOA, Districts will estimate the expected project outcomes using the methods as described in this section.
2. Implemented Projects: When change-outs are performed, Districts will revise earlier estimates, again using the methods as described in this section.

General Approach

Methods used in the Woodsmoke Reduction Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by activity type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

These methods account for the GHG emission reductions resulting from a home heating stove change-out from a fireplace, uncertified wood stove, or wood insert to a cleaner and more efficient home heating stove. In general, the GHG emission reductions are estimated in the Woodsmoke Reduction Benefits Calculator Tool using the approaches in Table 1. The Woodsmoke Reduction Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using the same inputs used to estimate GHG emission reductions. This quantification methodology accounts for avoided GHG emissions from uncertified wood stoves, wood inserts, and fireplaces used as primary sources of heat and GHG emissions associated with the use of cleaner, more efficient heating stoves. In general, the GHG emission reductions are calculated using the following approach:

Table 1. General Approach to GHG Quantification

GHG Emission Reductions from Change-Out
GHG Emission Reductions = GHG Emissions of Uncertified Wood Stove, Wood Insert, or Fireplace – GHG Emissions of New Heating Stove

The total project GHG, black carbon, and particulate emission reductions per Woodsmoke Reduction Program GGRF dollar requested and per total GGRF dollar requested, as described below.

- **Total Project GHG Emission Reductions** is equal to the sum total of each of the GHG emission reductions by stove type and are automatically summed in the Woodsmoke Reduction GHG Calculator Tool.

- **Total Project GHG Emission Reductions per Dollar of Woodsmoke Reduction Program GGRF Funds Requested** is calculated as shown in Table 2.

Table 2. General Approach to Quantification by Project change-out

Total Project GHG Emission Reductions per Dollar of Woodsmoke Reduction Program GGRF Funds Requested
$$\frac{\textit{Total Project GHG Emission Reductions in Metric Tons of } CO_2e}{\textit{Woodsmoke Reduction Program GGRF Funds Requested } (\$)}$$

Woodsmoke Reduction Program GGRF Funds Requested ($) for all projects is equal to the amount of GGRF dollars the District is requesting from the Woodsmoke Reduction Program. The Woodsmoke Reduction GHG Calculator Tool will provide the Total Project GHG Emission Reductions per Woodsmoke Reduction Program GGRF Dollar Requested.

Table 3. General Approach to Quantification by Project change-out

Total Project GHG Emission Reductions per Dollar of GGRF
$$\frac{\textit{Total Project GHG Emission Reductions in Metric Tons of } CO_2e}{\textit{Total GGRF Funds Requested } (\$)}$$

The Total GGRF Funds Requested ($) for all project features is equal to the sum of GGRF dollars the District is requesting for the project from the Woodsmoke Reduction Program, all GGRF dollars from CARB or other agencies that have previously been awarded to the same project, and any GGRF dollars from agencies other than CARB that the District has or plans to apply for. For a list of GGRF funded programs, go to: www.arb.ca.gov/cci-events. If no other GGRF funds are requested, this will be the same amount as the Woodsmoke Reduction Program GGRF Funds Requested. The Woodsmoke Reduction GHG Calculator Tool will provide the Total Project GHG Emission Reductions per GGRF Dollar Requested.

Emission Factors

A. Household Heating Needs and Stove-Specific Consumption Rates

The Woodsmoke Reduction Program funds the replacement of uncertified, inefficient wood burning stoves with cleaner-burning and more efficient residential heating stoves. For the purposes of estimating emission reductions, this quantification methodology assumes that households will require the same amount of useful heat in the baseline and project scenario. Benefits accrue as a result of the difference in the efficiency of existing and replacement stoves and relative improvement in emission rates of GHGs, $PM_{2.5}$, and black carbon.

1. Determine the California average annual household heating energy consumption from the U.S. EIA 2009 Residential Energy Consumption Survey.

2. Determine the California average efficiency of household heating using:
    a. California rates of use of different residential heating stoves from the U.S. Census 2015 American Community Survey 1-Year Estimates, California House Heating Fuel
    b. Residential heating stove efficiencies from the U.S. Energy Information Administration Heating Fuel Comparison Calculator for utility natural gas, electricity, and bottled, tank or LPG gas
    c. Residential wood stove efficiencies from U.S. EPA AP-42

3. Determine the California average household heating energy need if stoves were 100% efficient by multiplying the average annual household heating energy consumption derived in Step 1 by the average efficiency of household heating derived in Step 2.

4. Determine the average MMBtu demand of each stove type by dividing the California average household heating energy need if stoves were 100% efficient determined in Step 3 by the efficiencies of eligible existing and replacement stoves using:
    a. Efficiencies from Houk, J. and Tiegs, P. for fireplaces and propane or natural gas heating stoves.
    b. Efficiency from the U.S. Department of Energy Electric Resistance Heating for electric heating stoves.
    c. Efficiencies from U.S. EPA AP-42 for residential wood stoves.

    Efficiencies may vary from those used in Step 2 due to the broader stove categories used in the census compared to the specific existing and replacement stoves eligible under the Program.

5. For wood burning stoves, determine the annual wood use for each type of wood burning stove by dividing the average MMBtu demand for each stove type determined in Step 4 by the heating value of wood.

6. Calculate stove specific emissions using the MMBtu demands and wood use from Steps 5 and 6 and the fuel specific emission factors described in sections B and C below.

B.   Electricity GHG Emission Factor

For the purposes of quantification methodologies for agencies administering California Climate Investments, CARB developed a California grid average electricity emission factor based on total in-state and imported electricity emissions (in $MTCO_2e$) divided by total consumption (in kWh) as calculated in Equation 1.

Statewide electricity emissions data were obtained from the most recent edition of CARB's GHG Emission Inventory.[4] The total in-state electricity generation is combined with the total imported electricity to determine the total emissions for grid electricity. The total electricity consumption data was derived by summing electricity generation and net imports obtained from California Energy Commission's (CEC) California Energy Almanac.[5]

Equation 1: California Grid Average Electricity Emission Factor
$$EF = \frac{Electricity\ Emissions}{Electricity\ Consumption}$$

Where,			Units
Electricity Emissions	=	Total in-state electricity and imported electricity emissions	$MTCO_2e$
Electricity Consumption	=	Total California electricity generation and net imports	kWh

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[4] CARB California Greenhouse Gas Emissions Inventory – 2017 Edition
https://www.arb.ca.gov/cc/inventory/data/data.htm

[5] CEC California Energy Almanac
http://www.energy.ca.gov/almanac/electricity_data/electricity_generation.html

C. Heating Fuel GHG Emission Factors

Heating fuels for Woodsmoke Reduction projects are wood, natural gas, and propane. The heating fuel emission factors are derived from the United States Environmental Protection Agency's (U.S. EPA) Emission Factors for Greenhouse Gas Inventories, located at: https://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf.

In the absence of a mechanism to verify that the wood burned in an applicant's primary heating stove is waste material harvested pursuant to an approved timber management plan prepared in accordance with the Z'berg-Nejedly Forest Practice Act of 1973 or other locally or nationally approved plan and harvested for the purpose of forest fire fuel reduction or forest stand improvement, biogenic CO_2 is included in the calculation of GHG benefits for these stoves.

The Emission Factors for Greenhouse Gas Inventories uses the global warming potentials (GWP) from the IPCC Fourth Assessment Report. Gases are converted to $MTCO_2e$ by multiplying by their GWP and converting the units appropriately.

Gas	Units	100-year GWP
CO_2	kg/mmBtu	1
CH_4	kg/mmBtu	25
N_2O	kg/mmBtu	298

Equations Supporting the Woodsmoke Reduction Program

Methods used in the Woodsmoke Reduction GHG Calculator Tool for estimating GHG, black carbon, and particulate emission reductions are provided below using the equations below. Additional information about the emission factors used is available in the GHG Calculator Tool.

D.   GHG Emission Reductions from Change-Outs

The GHG emission reductions from the project are calculated as the difference between the baseline and project scenarios using Equation 2.

Equation 2: GHG Emission Reductions from Change-Outs

$$GHG = Q_{FNC} \times 203.68 + Q_{UNC} \times 6.09 + Q_{FC} \times 203.68 + Q_{UC} \times 6.09 + Q_{FPS} \times 203.65 + Q_{UPS} \times 6.06 + Q_{FHP} \times 159.46 + Q_{UHP} \times 11.27 + Q_{FE} \times 138.48 + Q_{UE} \times 9.86 + Q_{FP} \times 138.66 + Q_{UP} \times 10.22 + Q_{FNG} \times 139.88 + Q_{UNG} \times 11.44$$

Where,			Units
GHG	=	GHG benefit from all project change-outs	MTCO$_2$e
Q_{FNC}	=	Quantity of fireplaces replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{UNC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{FC}	=	Quantity of fireplaces replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{UC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{FPS}	=	Quantity of fireplaces replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{UPS}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{FHP}	=	Quantity of fireplaces replaced with ductless mini-split heat pump	Change-outs
Q_{UHP}	=	Quantity of uncertified wood stoves or wood inserts replaced with ductless mini-split heat pump	Change-outs
Q_{FE}	=	Quantity of fireplaces replaced with electric home heating stoves	Change-outs
Q_{UE}	=	Quantity of uncertified wood stoves or inserts replaced with electric home heating stoves	Change-outs
Q_{FP}	=	Quantity of fireplaces replaced with propane home heating stoves	Change-outs
Q_{UP}	=	Quantity of uncertified wood stoves or inserts replaced with propane home heating stoves	Change-outs
Q_{FNG}	=	Quantity of fireplaces replaced with natural gas home heating stoves	Change-outs
Q_{UNG}	=	Quantity of uncertified wood stoves or inserts replaced with natural gas home heating stoves	Change-outs
203.68	=	GHG emission reduction from replacing a fireplace with a certified non-catalytic wood stove or wood insert	MTCO$_2$e/ change-out
6.09	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with a certified non-catalytic wood stove or wood insert	MTCO$_2$e/ change-out
203.68	=	GHG emission reduction from replacing a fireplace with a certified catalytic wood stove or wood insert	MTCO$_2$e/ change-out
6.09	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with a certified catalytic wood stove or wood insert	MTCO$_2$e/ change-out

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		Equation 2: GHG Emission Reductions from Change-Outs Continued	
203.65	=	GHG emission reduction from replacing a fireplace with a certified pellet stove or pellet insert	$MTCO_2e$/ change-out
6.06	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with a certified pellet stove or pellet insert	$MTCO_2e$/ change-out
159.46	=	GHG emission reduction from replacing a fireplace with a ductless mini-split heat pump	$MTCO_2e$/ change-out
11.27	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with a ductless mini-split heat pump	$MTCO_2e$/ change-out
138.48	=	GHG emission reduction from replacing a fireplace with an electric home heating stove	$MTCO_2e$/ change-out
10.04	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with an electric home heating stove	$MTCO_2e$/ change-out
138.66	=	GHG emission reduction from replacing a fireplace with a propane home heating stove	$MTCO_2e$/ change-out
10.22	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with a propane home heating stove	$MTCO_2e$/ change-out
139.88	=	GHG emission reduction from replacing a fireplace with a natural gas home heating stove	$MTCO_2e$/ change-out
11.44	=	GHG emission reduction from replacing an uncertified wood stove or wood insert with a natural gas home heating stove	$MTCO_2e$/ change-out

E.   PM$_{2.5}$ Emission Reductions from Change-Outs

The PM$_{2.5}$ emission reductions from the project are calculated as the difference between the baseline and project scenarios using Equation 3.

Equation 3: PM$_{2.5}$ Emission Reductions from Change-Outs

$$PM_{2.5} = Q_{FNC} \times 3{,}052.56 + Q_{UNC} \times 469.24 + Q_{FC} \times 2{,}999.88 + Q_{UC} \times 416.55 + Q_{FPS} \times 3{,}061.08 + Q_{UPS} \times 477.75 + Q_{FHP} \times 2{,}328.94 + Q_{UHP} \times 391.45 + (Q_{FE} + Q_{FP} + Q_{FNG}) \times 2{,}018.42 + (Q_{UE} + Q_{UP} + Q_{UNG}) \times 339.25$$

Where,

			Units
$PM_{2.5}$	=	PM$_{2.5}$ emission reductions from all project change-outs	lbs
Q_{FNC}	=	Quantity of fireplaces replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{UNC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{FC}	=	Quantity of fireplaces replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{UC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{FPS}	=	Quantity of fireplaces replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{UPS}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{FHP}	=	Quantity of fireplaces replaced with ductless mini-split heat pump	Change-outs
Q_{UHP}	=	Quantity of uncertified wood stoves or wood inserts replaced with ductless mini-split heat pump	Change-outs
Q_{FE}	=	Quantity of fireplaces replaced with electric home heating stoves	Change-outs
Q_{UE}	=	Quantity of uncertified wood stoves or inserts replaced with electric home heating stoves	Change-outs
Q_{FP}	=	Quantity of fireplaces replaced with propane home heating stoves	Change-outs
Q_{UP}	=	Quantity of uncertified wood stoves or inserts replaced with propane home heating stoves	Change-outs
Q_{FNG}	=	Quantity of fireplaces replaced with natural gas home heating stoves	Change-outs
Q_{UNG}	=	Quantity of uncertified wood stoves or inserts replaced with natural gas home heating stoves	Change-outs
3,052.56	=	PM$_{2.5}$ emission reduction from replacing a fireplace with a certified non-catalytic wood stove or wood insert	lbs/change-out
469.24	=	PM$_{2.5}$ emission reduction from replacing an uncertified wood stove or insert with a certified non-catalytic wood stove or wood insert	lbs/change-out
2,999.88	=	PM$_{2.5}$ emission reduction from replacing a fireplace with a certified catalytic wood stove or wood insert	lbs/change-out
416.55	=	PM$_{2.5}$ emission reduction from replacing an uncertified wood stove or insert with a certified catalytic wood stove or wood insert	lbs/change-out
3,061.08	=	PM$_{2.5}$ emission reduction from replacing a fireplace with a certified pellet stove or pellet insert	lbs/change-out
477.75	=	PM$_{2.5}$ emission reduction from replacing an uncertified wood stove or wood insert with a certified pellet stove or pellet insert	lbs/change-out
2,328.94	=	PM$_{2.5}$ emission reduction from replacing a fireplace with a ductless mini-split heat pump	lbs/change-out
391.45	=	PM$_{2.5}$ emission reduction from replacing an uncertified wood stove or wood insert with a ductless mini-split heat pump	lbs/change-out

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		Equation 3: PM$_{2.5}$ Emission Reductions from Change-Outs Continued	
2,018.42	=	PM$_{2.5}$ emission reduction from replacing a fireplace with an electric, propane, or natural gas home heating stove	lbs/change-out
339.25	=	PM$_{2.5}$ emission reduction from replacing an uncertified wood stove or insert with an electric, propane, or natural gas home heating stove	lbs/change-out

F. Black Carbon Emission Reductions from Change-Outs

The black carbon emission reductions from the project are calculated as the difference between the baseline and project scenarios using Equation 4.

Equation 4: Black Carbon Emission Reductions from Change-Outs

$$BC = Q_{FNC} \times 381.57 + Q_{UNC} \times 58.65 + Q_{FC} \times 374.98 + Q_{UC} \times 52.07 + Q_{FPS} \times 382.63 + Q_{UPS} \times 59.72 + Q_{FHP} \times 291.12 + Q_{UHP} \times 48.93 + (Q_{FE} + Q_{FP} + Q_{FNG}) \times 252.30 + (Q_{UE} + Q_{UP} + Q_{UNG}) \times 41$$

Where,

			Units
BC	=	Black carbon emission reductions from all project change-outs	lbs
Q_{FNC}	=	Quantity of fireplaces replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{UNC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{FC}	=	Quantity of fireplaces replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{UC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{FPS}	=	Quantity of fireplaces replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{UPS}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{FHP}	=	Quantity of fireplaces replaced with ductless mini-split heat pump	Change-outs
Q_{UHP}	=	Quantity of uncertified wood stoves or wood inserts replaced with ductless mini-split heat pump	Change-outs
Q_{FE}	=	Quantity of fireplaces replaced with electric home heating stoves	Change-outs
Q_{UE}	=	Quantity of uncertified wood stoves or inserts replaced with electric home heating stoves	Change-outs
Q_{FP}	=	Quantity of fireplaces replaced with propane home heating stoves	Change-outs
Q_{UP}	=	Quantity of uncertified wood stoves or inserts replaced with propane home heating stoves	Change-outs
Q_{FNG}	=	Quantity of fireplaces replaced with natural gas home heating stoves	Change-outs
Q_{UNG}	=	Quantity of uncertified wood stoves or inserts replaced with natural gas home heating stoves	Change-outs
381.57	=	Black carbon emission reduction from replacing a fireplace with a certified non-catalytic wood stove or wood insert	lbs/change-out
58.65	=	Black carbon emission reduction from replacing an uncertified wood stove or insert with a certified non-catalytic wood stove or wood insert	lbs/change-out
374.98	=	Black carbon emission reduction from replacing a fireplace with a certified catalytic wood stove or wood insert	lbs/change-out
52.07	=	Black carbon emission reduction from replacing an uncertified wood stove or insert with a certified catalytic wood stove or wood insert	lbs/change-out
382.63	=	Black carbon emission reduction from replacing a fireplace with a certified pellet stove or pellet insert	lbs/change-out
59.72	=	Black carbon emission reduction from replacing an uncertified wood stove or wood insert with a certified pellet stove or pellet insert	lbs/change-out
291.12	=	Black carbon emission reduction from replacing a fireplace with a ductless mini-split heat pump	lbs/change-out
48.93	=	Black carbon emission reduction from replacing an uncertified wood stove or wood insert with a ductless mini-split heat pump	lbs/change-out

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Equation 4: Black Carbon Emission Reductions from Change-Outs Continued

252.30	=	Black carbon emission reduction from replacing a fireplace with an electric, propane, or natural gas home heating stove	lbs/change-out
42.41	=	Black carbon emission reduction from replacing an uncertified wood stove or insert with an electric, propane, or natural gas home heating stove	lbs/change-out

Co-benefit Equations Supporting the Woodsmoke Reduction Program

Methods used in the Woodsmoke Reduction GHG Calculator Tool for estimating the co-benefits and key variables $PM_{2.5}$, NO_x, and ROG for air pollutant emissions based on fuel type. Additional information about the emission factors used is available in the GHG Calculator Tool.

G. NO_x Emission Reductions from Change-Outs

The NO_x emission reductions from the project are calculated as the difference between the baseline and project scenarios using Equation 5.

Equation 5: NO_x Emission Reductions from Change-Outs

$$NO_X = Q_{FNC} \times 323.18 + Q_{UNC} \times 17.52 + Q_{FC} \times 327.12 + Q_{UC} \times 21.46 + Q_{FPS} \times 298.28 + Q_{UPS} \times -7.37 + Q_{FHP} \times 261.62 + Q_{UHP} \times 32.38 + Q_{FE} \times 226.74 + Q_{UE} \times 28.06 + Q_{FP} \times 210.33 + Q_{UP} \times 11.65 + Q_{FNG} \times 217.55 + Q_{UNG} \times 18.88$$

Where,   Units
NO_x	=	NO_X benefit from all project change-outs	lbs
Q_{FNC}	=	Quantity of fireplaces replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{UNC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{FC}	=	Quantity of fireplaces replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{UC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{FPS}	=	Quantity of fireplaces replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{UPS}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{FHP}	=	Quantity of fireplaces replaced with ductless mini-split heat pump	Change-outs
Q_{UHP}	=	Quantity of uncertified wood stoves or wood inserts replaced with ductless mini-split heat pump	Change-outs
Q_{FE}	=	Quantity of fireplaces replaced with electric home heating stoves	Change-outs
Q_{UE}	=	Quantity of uncertified wood stoves or inserts replaced with electric home heating stoves	Change-outs
Q_{FP}	=	Quantity of fireplaces replaced with propane home heating stoves	Change-outs
Q_{UP}	=	Quantity of uncertified wood stoves or inserts replaced with propane home heating stoves	Change-outs
Q_{FNG}	=	Quantity of fireplaces replaced with natural gas home heating stoves	Change-outs
Q_{UNG}	=	Quantity of uncertified wood stoves or inserts replaced with natural gas home heating stoves	Change-outs
323.18	=	NO_X emission reduction from replacing a fireplace with a certified non-catalytic wood stove or wood insert	lbs/change-out
17.52	=	NO_X emission reduction from replacing an uncertified wood stove or wood insert with a certified non-catalytic wood stove or wood insert	lbs/change-out
327.12	=	NO_X emission reduction from replacing a fireplace with a certified catalytic wood stove or wood insert	lbs/change-out

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		Equation 5: NO$_X$ Emission Reductions from Change-Outs Continued	
21.46	=	NO$_X$ emission reduction from replacing an uncertified wood stove or wood insert with a certified catalytic wood stove or wood insert	lbs/change-out
298.28	=	NO$_X$ emission reduction from replacing a fireplace with a certified pellet stove or pellet insert	lbs/change-out
-7.37	=	NO$_X$ emission reduction from replacing an uncertified wood stove or wood insert with a certified pellet stove or pellet insert	lbs/change-out
261.62	=	NO$_X$ emission reduction from replacing a fireplace with a ductless mini-split heat pump	lbs/change-out
32.38	=	NO$_X$ emission reduction from replacing an uncertified wood stove or wood insert with a ductless mini-split heat pump	lbs/change-out
226.74	=	NO$_X$ emission reduction from replacing a fireplace with an electric home heating stove	lbs/change-out
28.06	=	NO$_X$ emission reduction from replacing an uncertified wood stove or wood insert with an electric home heating stove	lbs/change-out
210.33	=	NO$_X$ emission reduction from replacing a fireplace with a propane home heating stove	lbs/change-out
11.65	=	NO$_X$ emission reduction from replacing an uncertified wood stove or wood insert with a propane home heating stove	lbs/change-out
217.55	=	NO$_X$ emission reduction from replacing a fireplace with a natural gas home heating stove	lbs/change-out
18.88	=	NO$_X$ emission reduction from replacing an uncertified wood stove or wood insert with a natural gas home heating stove	lbs/change-out

H.   ROG Emission Reductions from Change-Outs

The ROG emission reductions from the project are calculated as the difference between the baseline and project scenarios using Equation 6.

Equation 6: ROG Emission Reductions from Change-Outs

$$ROG = Q_{FNC} \times 2{,}413.60 + Q_{UNC} \times 769.94 + Q_{FC} \times 2{,}371.40 + Q_{UC} \times 727.75 + Q_{FPS} \times 2{,}581.78 + Q_{UPS} \times 938.13 + Q_{FHP} \times 1{,}936.01 + Q_{UHP} \times 703.27 + Q_{FE} \times 1{,}677.88 + Q_{UE} \times 609.50 + Q_{FP} \times 1{,}676.97 + Q_{UP} \times 608.59 + Q_{FNG} \times 1{,}677.39 + Q_{UNG} \times 609.01$$

Where,			**Units**
ROG	=	ROG benefit from all project change-outs	lbs
Q_{FNC}	=	Quantity of fireplaces replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{UNC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified non-catalytic wood stoves or wood inserts	Change-outs
Q_{FC}	=	Quantity of fireplaces replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{UC}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified catalytic wood stoves or wood inserts	Change-outs
Q_{FPS}	=	Quantity of fireplaces replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{UPS}	=	Quantity of uncertified wood stoves or wood inserts replaced with certified pellet stoves or pellet inserts	Change-outs
Q_{FHP}	=	Quantity of fireplaces replaced with ductless mini-split heat pump	Change-outs
Q_{UHP}	=	Quantity of uncertified wood stoves or wood inserts replaced with ductless mini-split heat pump	Change-outs
Q_{FE}	=	Quantity of fireplaces replaced with electric home heating stoves	Change-outs
Q_{UE}	=	Quantity of uncertified wood stoves or inserts replaced with electric home heating stoves	Change-outs
Q_{FP}	=	Quantity of fireplaces replaced with propane home heating stoves	Change-outs
Q_{UP}	=	Quantity of uncertified wood stoves or inserts replaced with propane home heating stoves	Change-outs
Q_{FNG}	=	Quantity of fireplaces replaced with natural gas home heating stoves	Change-outs
Q_{UNG}	=	Quantity of uncertified wood stoves or inserts replaced with natural gas home heating stoves	Change-outs
2,413.60	=	ROG emission reduction from replacing a fireplace with a certified non-catalytic wood stove or wood insert	lbs/change-out
769.94	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with a certified non-catalytic wood stove or wood insert	lbs/change-out
2,371.40	=	ROG emission reduction from replacing a fireplace with a certified catalytic wood stove or wood insert	lbs/change-out
727.75	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with a certified catalytic wood stove or wood insert	lbs/change-out
2,581.78	=	ROG emission reduction from replacing a fireplace with a certified pellet stove or pellet insert	lbs/change-out
938.13	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with a certified pellet stove or pellet insert	lbs/change-out
1,936.01	=	ROG emission reduction from replacing a fireplace with a ductless mini-split heat pump	lbs/change-out
703.27	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with a ductless mini-split heat pump	lbs/change-out

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		Equation 6: ROG Emission Reductions from Change-Outs Continued	
1,677.88	=	ROG emission reduction from replacing a fireplace with an electric home heating stove	lbs/change-out
609.50	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with an electric home heating stove	lbs/change-out
1,676.97	=	ROG emission reduction from replacing a fireplace with a propane home heating stove	lbs/change-out
608.59	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with a propane home heating stove	lbs/change-out
1,677.39	=	ROG emission reduction from replacing a fireplace with a natural gas home heating stove	lbs/change-out
609.01	=	ROG emission reduction from replacing an uncertified wood stove or wood insert with a natural gas home heating stove	lbs/change-out

Section C. References

The following references were used in the development of this Quantification Methodology and the Woodsmoke Reduction Benefits Calculator Tool.

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